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THE EFFECTS OF NOISE AND OF LOSS OF SLEEP UPON THE OBSERVATION --ETC(U)
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SUMMARY

Three ~~3~~ groups of 12 naval ratings had to monitor 3 sources of signals, and to report each time they detected a signal. A source was checked by pressing the corresponding key and looking for a dull red flash. During every 4 min one source always presented 12 signals, another source always presented 6 signals, and the third source always presented 2 signals. The signals were presented at irregular intervals, one at a time. They remained available for detection until they were reported. Two groups of ratings were restricted to a single check of 1 of the 3 sources every 2 sec. A flashing green light indicated the start of each 2 sec. The third group could check each source as often as desired.

The main results are for the 2 groups which were restricted to one check every 2 sec. One group worked with and without noise. Noise greatly increased the proportion of checks of the most frequent source of signals (Figure 1). The other group worked after a night without sleep and after normal sleep. Loss of sleep prevented the normal increase in the proportion of checks of the most frequent source of signals, which was found in quiet after normal sleep (Figure 1).

When a source was checked, the dull red flashing signal was not always reported. Sometimes the man checked the source again at the next opportunity, and then reported the signal. Immediate reports are called hits. Reports after a repeat check are called unsure hits. The man was taken to have missed the signal if he failed to report the signal at the first check, and subsequently checked another source before returning to the first source and reporting the signal.

In all conditions the number of hits was smaller in the last half of each 32 min experimental period than in the first half. In quiet after normal sleep, it was the number of unsure hits which increased in the second half of the period. In noise it was the number of misses (Table 3). After loss of a night's sleep there were always more unsure hits than in any other condition. The proportion of unsure hits was particularly large in the second half of the period after loss of sleep (Table 4).

Thus noise has a beneficial effect in making the man concentrate more on the most probable source of signals. But noise has a detrimental effect in increasing the number of misses in the second half of the experimental period. Whereas loss of a night's sleep has only detrimental effects. It stops the man from concentrating more on the most probable source of signals. And it makes him require more evidence before he reports a signal.

INTRODUCTION

1. The new visual sonar displays present the man with a mass of information. In order to detect targets, the man has to search for them. This is the case whether or not a computer places markers on the display to indicate to the man the areas where he should search.

2. An experimental technique for studying looking strategies was developed at the US Naval Research Laboratory (Holland, 1957). Instead of recording eye movements, which have to be related to what is happening in the display, the man is given a key to press each time he wants to look. In Holland's original experiment, there is only a single source of signals. Pressing the key shows the man whether or not there is a signal from the source.

3. The method was developed by Broadbent (1963), who gave the man 3 keys to press, one corresponding to each of 3 sources of signals. The man could press only one key at a time, just as he can concentrate upon only one part of a sonar display at a time. Thus the task is analogous to a sonar display with 3 markers.

4. The present experiment uses a similar task with 3 sources of signals and 3 response keys. In the standard paced condition looks are allowed only once every 2 sec. This corresponds roughly to the time which a sonar man requires to decide whether or not a small area of visual noise contains a superimposed signal.

5. The experiment is a further development of Broadbent's (1963) method, in that the probability of a signal is different for each of the 3 sources. This relates to the unequal probabilities of signals on a visual sonar display. Signals are most probable in the middle distance. In the far distance physical limitations reduce the chances of a detectable signal. Undetected targets are also unlikely to appear close to the ship. The probability of a signal in a particular area can also be increased by information transmitted from the operations room.

Previous work

6. Holland's (1957) "observing response" technique is derived from operant training procedures. However the technique has proved disappointing, especially for the analysis of behaviour in multi-source tasks. In contrast with expectations based on the findings of more conventional approaches, a number of studies using this technique have failed to find any systematic relationship between the distribution of observing responses and the relative probabilities of faults on different sources (Blair and Kaufman, 1959: Hickey and Blair, 1959). More recently, Senders (1965) has succeeded in demonstrating such a relationship when the overall signal load was very high, his subjects making more fixations of sources having a high probability of signal occurrence. An important variable seems to be the "cost" of making an observing response. Hamilton (1969) found a consistent relation between sampling frequencies and source probability in a 3-source task when either (a) the overall fault rate was high (as in the Senders experiment), or (b) the allowable rate of sampling was restricted by external pacing. Since both these procedures have the effect of increasing the probability of a fault occurring on any sample, the need to use a selective strategy becomes greater. Given suitable task parameters, then, the observing response technique does seem capable of providing a measure of attention deployment which is both objective and independent of detection processes. Furthermore, once the subject is using a selective strategy to sample the display, it becomes meaningful to examine changes in that behaviour as a function of environmental and task variables.

7. The present study examines the effects of two common stresses, noise and sleep loss, on performance in this kind of task. Previous experiments using a conventional dual-task monitoring/tracking situation (Hockey, 1970a, 1970b, 1970c; Hamilton and Copeman, 1970) have suggested changes in attention deployment as a function of both these stresses. Noise has the effect of enhancing performance on high priority task components and causing impairment of low priority activities. Loss of sleep, on the other hand, produced performance changes that could be interpreted as opposite to those of noise, impairment being greater on the high priority aspects of the complex task. The effects are thus selective, in that it is the pattern of performance over the task that is principally affected, rather than a simple overall reduction in efficiency.

8. The evidence from these studies has been discussed in terms of phasic arousal shifts, since sleep loss and noise are known to interact negatively when combined as stresses in other tasks, while sleep loss produces clear physiological indications of reduced activation. In addition, a motivating variable, incentive, is known to abolish the detrimental effects of sleep loss, but to augment those of noise in performance of the five-choice serial reaction task. Broadbent (1971) provides a fuller discussion of this evidence.

9. The dual-task results seem best interpreted, then, as indicating a monotonic relationship between level of arousal and what we have called the selectivity of attention. As arousal is increased, attentional sampling becomes more selective and focussed on the more important aspects of the task. With a decrease in arousal attention broadens and sampling becomes less selective. However, in our interpretation of these results, we have been obliged to make inferences about attentional sampling patterns on the basis of data relating to changes in the relative efficiency of responses to critical events. Thus, it is not clear whether the changes we have been discussing do indeed occur in the selection of different sources of information, or at some later stage in the system (in response selection).

10. The present study is an attempt to examine the information-selection interpretation of the effects of arousal shifts more directly. Using a technique such as Hamilton's we can measure actual sampling frequencies for sources of different priority, and the extent and direction of changes in these patterns of selection with exposure to stress. In these experiments priority is manipulated by giving sources different fault probabilities, since frequent sampling is a more necessary activity for high probability sources than for low. If the effects observed in the dual-task studies are the result of changes in information-selection patterns, then we would expect noise to increase the relative frequency of high probability source sampling and sleep loss to reduce the normal bias towards this source. For completeness, a record was also kept of the sequence of responses produced by the subject in the correction of faults present in the system (ie detection performance). Hamilton (1969) did not analyse this aspect of performance, and, in any case, used clearly discriminable signals. However, Broadbent (1963) reports that nearly all subjects required more observations of an active source (with a signal present) towards the end of a task session. If the signal (or fault) is made difficult to detect, we would expect more errors of this kind, so that it becomes possible to examine changes in detection efficiency separately from those concerned with the distribution of attention. No clear predictions can be made regarding the effects of noise and sleep loss on detection behaviour in this task, though the data may assist the interpretation of any changes in the principle dependent variable, that of selectivity in sampling.

METHOD

Testing Conditions and Subjects

11. Different groups of subjects were used in the two experiments. They were tested

individually in a dimly-lit room, seated in a comfortable chair 5 ft from the display. Smoking was allowed, but watches removed. An audiometric screening procedure was used to eliminate subjects with hearing loss as great as 35dB on one ear or 30dB on both ears. Those with suspected visual defects were also eliminated.

The monitoring task

12. The task was generally the same as that used and described by Hamilton (1969). The display, in this case, consisted of a triangular arrangement of three light sources, 75 cm apart. The subject was equipped with a control panel with sampling buttons corresponding to each of the lights. Pressing one of these buttons completed the circuit for that light for a brief period (50 msec) enabling the state of that source to be checked. In the "normal" state each light was off, but occasional "faults" were fed into the display, and these were indicated by the occurrence of a dull red flash upon sampling. The intensity of the flash was adjusted in pilot studies to produce about 50% of immediate corrections. These faults were introduced manually by closing a relay, only one fault being allowed in the circuit at any one time. A holding circuit ensured that the fault remained in the channel until eventually corrected by the subject. This he did by pressing one of three correcting buttons on the control panel after having observed a fault. This procedure ensured that the sources were not being sampled without regard to the actual occurrence of faults, and made the task more realistic.

13. The overall fault rate was 5/min, distributed over the three sources in the ratio 6:3:1, the allocation of fault rates to the actual locations being balanced across subjects. Sampling responses were recorded by counters and read every 4 min. In addition, the sequence of samples following the introduction of each fault into the system was recorded and analysed, to provide a measure of detection behaviour.

Instructions to Subjects

14. The subjects were asked to imagine themselves in the position of a machine maintenance operator, with three machines to look after. The state of a particular machine could be checked by pressing the appropriate sampling button: a dull red flash would indicate that the machine was not functioning properly. They were told that faults could occur on any of the three machines but that only one was likely to be faulty at any one time. Like real machines, faults may occur more regularly in some places than others, and they should bear this in mind when checking, since the object was to detect and correct each fault as quickly as possible. A fault would remain in the system until corrected. (No feedback was given on the length of time a fault had remained undetected).

Pacing

15. A green light was located at the centre of the display, acting as a pacing device. It was connected to a timer to produce a dull green flash every 2 sec. Both paced and unpaced conditions were used in Experiment I, the paced condition only in Experiment II. Subjects in the unpaced group were instructed to sample at a rate they found manageable, and in the paced groups to make one sample each time the green light came on (since the room was dimly illuminated there was no need to look directly at the pacing light in order to time their sampling.

EXPERIMENT I

16. The way in which noise affects selectivity, from the dual-task studies, seems to be by increasing the normal bias towards probable or important sources of information. Experiment I attempts to demonstrate this effect more directly, as a change in the

relative frequency of sampling responses towards the high probability source. It also incorporates a replication of part of Hamilton's (1969) experiment, concerning the effect of pacing. Any effect of noise is likely to be greater in the paced condition since there should be a more pronounced attentional bias already present.

Method

Subjects

17. Twentyfour enlisted men from the Royal Navy were used. Ages ranged from 18 to 24 years.

Noise

18. The noise used in these experiments was amplified valve noise, having approximately equal energy per octave in the range 62.5 to 4000 Hz. The output was attenuated by 3dB per octave up to 1000 Hz, in accordance with normal hearing-hazard precautions. The noise was projected into the testing room through a pair of wall-mounted loudspeakers. The SPL's used in the experiment were 70 dBA (designated "quiet") and 100 dBA ("noise").

Design and Procedure

19. The subjects were randomly allocated to paced or unpaced conditions, 12 to each group. Both groups received the two levels of noise, in a counter-balanced order. Each session lasted for 32 min, divided into eight 4 min periods for analysis. The design was thus a 2x2x8 factorial, with repeated measures on the second two factors (noise conditions and task periods). Testing was always carried out between 0800 and 1100 hr. The two test sessions were one week apart to minimise carry-over effects. Practice was always in quiet, and consisted of a preliminary orientation period followed by one complete run through. The principal measure of performance, the degree of selectivity, was defined as the percentage of sampling responses made on the high probability source in each period since preliminary trials showed very little sampling differences between the two low probability sources. In addition, an analysis was made of detection behaviour (see below), and overall sampling rate (number of samples/4 min period) was scored for the unpaced conditions.

Results and Discussion

Selectivity

20. Table 1 shows the degree of selectivity for each level of pacing and noise, over the eight task periods. There are very clear main effects of noise, $\underline{F}\ (1,330) = 9.21$; $\underline{p} < 0.01$, pacing $\underline{F}\ (1,22) = 12.36$; $\underline{p} < 0.01$ and periods, $\underline{F}\ (7,330) = 4.11$; $\underline{p} < 0.01$. All interactions are also significant at the $\underline{p} < 0.01$ level. The increase in selectivity with pacing apparent in the data for the two groups in quiet confirms Hamilton's (1969) result. In addition, the present findings demonstrate an increase in the selectivity of sampling under noise, and that the effect is much more marked when the rate of sampling is externally paced. Time spent at the task increases all the effects present.

Sampling rate

21. For the unpaced condition Table 2 shows the marked increase in sampling rate in successive 4 min periods, though there are no differences between noise and quiet. A Wilcoxon $\underline{T}$ test (Siegel, 1956), carried out on the total samples made for first and second halves of the session confirms this observation ($\underline{p} > 0.05$) for the noise/quiet

comparisons for both halves). The increase in sampling rate over time is, however, significant for both noise and quiet ($p < 0.01$). The absence of an effect of noise on free sampling rate confirms the similar result obtained by Broadbent (1963) in a three-source observing response task with equal probabilities on each source. It is clearly not the rate of sampling which is affected by noise, but the way in which sampling responses are distributed over the task.

22. The data confirm that the tendency to sample the high probability information source more often is increased by the presence of loud noise. Since the effect does not appear when subjects can set their own rate of sampling, the measure of selectivity in an unrestricted situation may represent an unrealistic estimate of any real underlying attention priorities. As in the earlier studies of Blair and Kaufman (1959) and Hickey and Blair (1959), the time cost associated with suboptimal sampling strategies is very low in the unpaced situation since all sources may be checked in a period of about 2 sec.

Detection analysis

23. From the records of sampling responses following the introduction of faults into the system, 3 distinct types of detection pattern were evident: (a) faults were corrected on the first opportunity, (b) they were missed, then corrected on a subsequent, independent observation of the source, (c) they were corrected after 2 successive observations of the source. (a) and (b) can be seen to correspond to 'hits' and 'misses' in more conventional signal detection situations, while (c) represents a class of responses which seem fairly common in observing response tasks (Broadbent, 1963) and suggest a state of uncertainty above the presence or absence of a fault. The subject may be regarded as requiring further information before coming to a decision. These 'repeat' detection responses will be called 'unsure hits'. Table 3 presents a summary of the detection analysis, in terms of the percentage of all corrections associated with each type of response, for the 2 paced conditions (the sampling rates in the unpaced conditions were too fast for reliable manual recording of the detection sequences). The data are shown separately for each half of the test.

24. A number of points are of interest. Both conditions show a drop in hits from the first to the second half of the test (Wilcoxon T test, $p < 0.05$ for both noise and quiet). The patterns of decrement are different, however. For quiet, it is reflected in a corresponding rise in unsure hits ($p < 0.05$) with no change in misses, whereas, for noise, it is misses which show the increase ($p < 0.05$), with no change in unsure hits. The difference between the two conditions is more easily described as a reduction in the use of the repeat response (unsure hits) in noise, particularly in the second half of the task ($p < 0.01$).

25. The significance of these changes is not clear at this point, though Broadbent (1963) also found an increase in the proportion of repeat samples with time at work (under normal conditions). Taken together with the failure for misses to increase in quiet, this result may offer some support to the view that the usual vigilance decrement is due to changes in decision criteria, rather than to a drop in perceptual efficiency (Broadbent, 1971). The reduction in the number of unsure hits in noise is also consistent with the findings of Broadbent and Gregory (1963) in a conventional vigilance task, that, in noise, subjects tended to make less use of intermediate (uncertain) categories when giving confidence ratings for their decisions.

26. We thus have two seemingly independent effects of noise in this task. Firstly, it increases the likelihood of sampling high probability sources for information. Secondly, irrespective of which source is, in fact, sampled, it decreases the likelihood of making a doubtful judgment about the presence or absence of a fault on that source.

EXPERIMENT II

27. A second experiment was carried out, using only the paced version of the task, to examine the effects of a reduction in arousal level brought about by a night without sleep. If noise increases differences between normal sampling priorities, then from our interpretation of the dual-task studies, we would expect sleep loss to attenuate these differences. We may also expect corresponding changes in detection behaviour, possibly an increase in the proportion of repeat samples with sleep loss.

Method

Subjects

28. Twelve enlisted men from the Royal Navy were used. Ages ranged from 19 to 24 years.

Sleep loss

29. Subjects were kept awake for one complete night in small groups under close supervision, and tested the following morning. All testing was again carried out between 0800 and 1100 hr after an average period of 26 hr without sleep.

Design and Procedure

30. A 2x8 repeated measures factorial design was used, all subjects performing the task under both conditions of sleep ration (normal sleep and no sleep), with eight 4 min periods as in Experiment I. The order of sleep conditions was counterbalanced. Practice, as before, consisted of a brief orientation session followed by one complete run (under normal sleep conditions). The two test sessions, which were one week apart, were carried out in the presence of 70 dBA noise. This served the purposes of enabling comparison of the control conditions of Experiments I and II, and also masking apparatus sounds from the next room.

Results and Discussion

Selectivity

31. Analysis of variance revealed significant effects of sleep loss, $\underline{F}$ (1,65) = 5.68; $\underline{p} < 0.05$, periods, $\underline{F}$ (7,165) = 10.31; $\underline{p} < 0.001$, and their interaction, $\underline{F}$ (7,165) = 8.60; $\underline{p} < 0.001$. Loss of sleep results in a reduction in selectivity, and the difference becomes more apparent with time at work. The data, together with those from the paced condition of Experiment I are illustrated in Figure 1 for comparison. The two stresses are quite clearly affecting selectivity in opposing directions, both changes increasing with time.

Detection analysis

32. Table 4 shows the breakdown of fault detection responses into hits, unsure hits and misses, as for Experiment I. Wilcoxon $\underline{T}$ tests show that the same effects of time at work occur in the control (sleep) condition as in Experiment I; a decrease in hits ($\underline{p} < 0.05$), no change in misses and an increase in unsure hits ($\underline{p} < 0.05$), while the same general pattern of first/second half changes is found with sleep loss (both $\underline{p} < 0.01$). In addition, the overall proportion of hits is reduced for sleep loss ($\underline{p} < 0.01$), while the number of unsure hits is increased ($\underline{p} < 0.01$). This is true even if we take the proportional measure: unsure hits/(unsure hits + misses) because of the difference in

hits. As with the selectivity data, these changes show an opposite trend to those for noise.

GENERAL DISCUSSION

33. The effects of noise and sleep loss on the pattern of sampling responses in these experiments complement those found with the dual-task situation, and point towards an explanation of the effect of arousal shifts on monitoring performance in terms of changes in the information-selection strategies used by subjects. The observing response task shows this effect more clearly, as a directly measurable change in the frequency with which different sources are selected for attention, though it is far from clear how these changes in attention come about. One possibility is that noise and sleep loss have a direct effect on the underlying subjective probabilities associated with the occurrence of faults on each source, increasing or decreasing the bias towards those which are more likely to provide critical information.

34. If we examine the data on detection behaviour the situation is more complicated, however. It is not immediately apparent how these changes are related to those occurring in selectivity, or even if the two effects are related: clearly, it would be parsimonious to postulate a common mechanism for the two findings particularly in view of the opposite effects of noise and sleep loss in each. Broadbent (1971) suggests that sampling responses in observing response tasks may be of two types; either definite **decisions** to observe a particular source, or random choices of a source on the basis of insufficient information (since the sampling response cannot be withheld in the paced situation). The results of the detection analysis indicate that noise increases the tendency to make definite decisions (hits or misses) about the need for a fault to be corrected while sleep loss results in a higher proportion of doubtful decisions. If these changes in decision criteria also operate in the selection of sources for sampling, then one could expect the proportion of definite decisions to observe a source to be increased in noise (and correspondingly decreased with loss of sleep). Such a mechanism could perhaps produce the observed changes in information-selection patterns if the bias towards the definite decisions was stronger for sources of high probability, though the details of the relationship between the two processes are not known. It is clearly of some theoretical significance to know whether the observed changes in selectivity with shifts of arousal are indeed due indirectly to an effect on the use of doubtful decision categories, or to a direct effect of arousal on subjective probabilities. The relationship between decision criteria and attention patterns presents an interesting research problem, though as yet there is no direct evidence on it. Hamilton's adaption of the observing response situation may provide one useful technique for looking more closely at this problem.

35. Whatever the basis for the effect, however, the present experiments do demonstrate opposing changes in attention patterns with noise and sleep loss. If these stresses can be regarded as producing opposite changes in the level of arousal, as suggested, then the findings offer strong support to the idea of a monotonic increase in the selectivity of attention from low to high arousal levels. Such a change in information-selection strategies could well underly the classical inverted-U relationship between arousal and efficiency, and the Yerkes-Dodson law. Under-arousal will result in inefficiency because of insufficient sampling of relevant task stimuli, whereas over-arousal, through a high degree of selectivity, will result in inefficiency for a different reason. Skilled performance at any level depends on the integration of information from different sources; a high level of selectivity may have the effect of preventing all but the most relevant sources of information from being processed, and result in a breakdown of task integration. Furthermore, the optimum level of selectivity implied by this will vary for different tasks, so that a high level of selectivity will have less of an adverse effect on a simple task involving only one or two sources of relevant information, as predicted by the Yerkes-Dodson law.

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TABLE 1

Index of Selectivity (Mean Percentage of Samples of the High Probability Source) in successive 4 min periods for Experiment I

	TASK PERIOD							
CONDITION	1	2	3	4	5	6	7	8
Unpaced								
Quiet	34.7	34.1	33.8	35.2	36.3	36.4	36.8	37.4
Noise	35.5	34.7	35.1	35.1	35.1	37.5	37.7	37.6
Paced								
Quiet	35.8	37.5	38.4	39.5	39.8	40.6	39.4	40.1
Noise	35.8	38.9	40.9	41.8	43.3	44.2	44.9	44.8

TABLE 2

Sampling rates for the Unpaced Conditions of Experiment I, showing the mean number of Observations made in Quiet and Noise during successive 4 min periods of the Task

	TASK PERIOD							
CONDITION	1	2	3	4	5	6	7	8
Quiet	343	348	360	370	373	388	394	397
Noise	346	350	357	360	371	390	399	402

TABLE 3

Detection Performance for the Paced Conditions of Experiment I for each half of the Test, showing the mean percentage of faults detected immediately (Hits), after a repeat observation (Unsure Hits) or on a later observation (Misses)

CONDITION	1st Half Hits	1st Half Unsure Hits	1st Half Misses	2nd Half Hits	2nd Half Unsure Hits	2nd Half Misses
Quiet	62.9	11.8	25.3	49.4	24.5	26.1
Noise	62.5	9.8	27.7	52.8	8.6	38.6

TABLE 4

Detection Performance for Experiment II for each Half of the Test

CONDITION	1st Half			2nd Half		
	Hits	Unsure Hits	Misses	Hits	Unsure Hits	Misses
Sleep	69.2	11.2	19.6	60.5	22.5	17.0
No Sleep	60.5	24.9	14.6	45.7	36.5	17.8

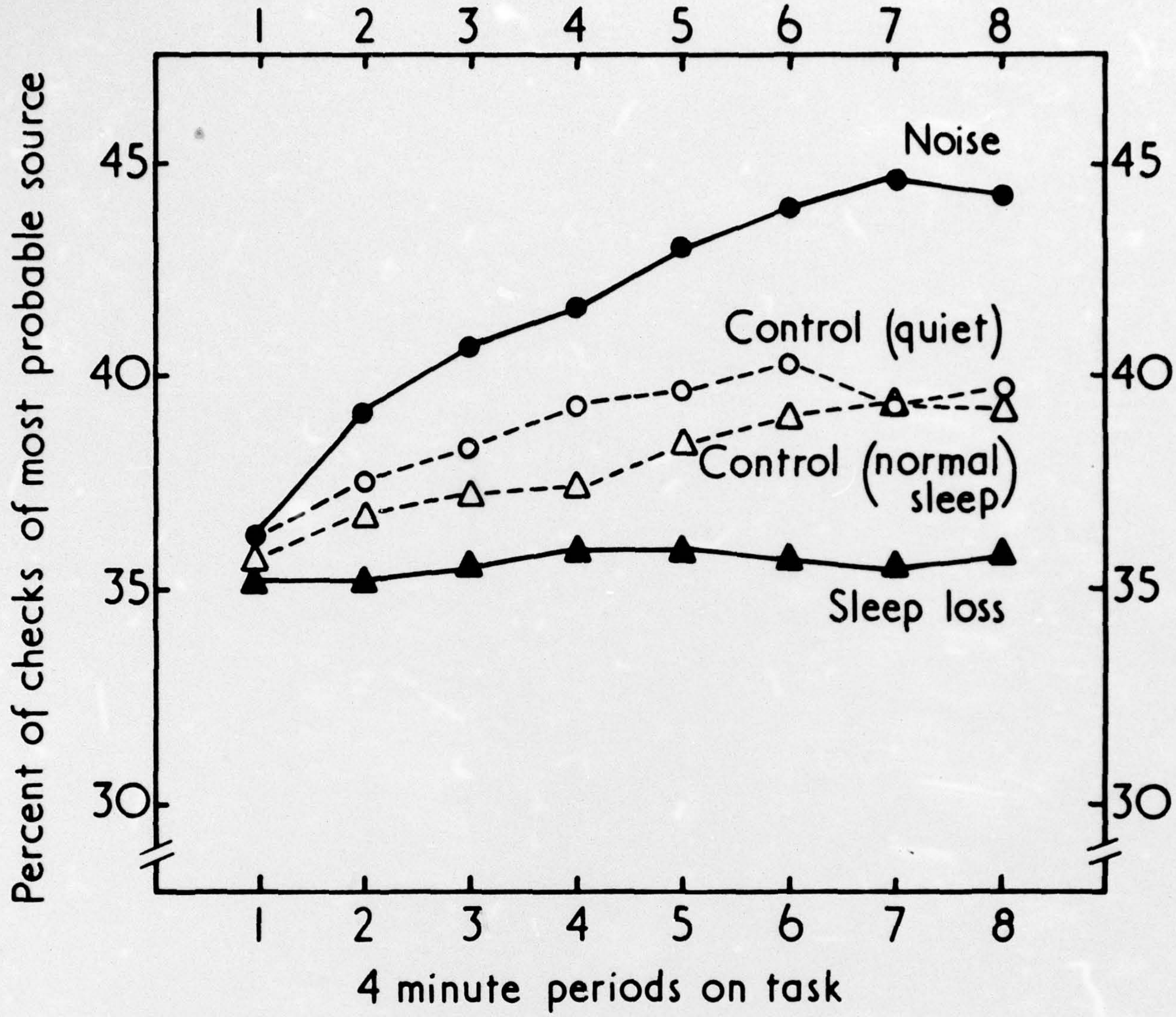

Figure 1. Comparison of the effects of noise (Experiment I) and sleep loss (Experiment II) on the percentage of checks of the high probability source in each 4 min period.